120 AP

Oil Adhesion Testing - Recent Results

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"Oil Adhesion Testing: Recent Results", in Proceedings of the Nineteenth Arctic Marine Oilspill Program Technical Seminar, Environment Canada, Ottawa, Ontario, pp 9-27, 1996.

ABSTRACT

The results of an experiment to determine the effects of different surface materials on adhesion measurements are presented. In this experiment six different surface materials (stainless steel, glass, plastic, Teflon, wood, and ceramic) were tested with five different oils. The results indicate that the relative adhesiveness of the oils is unaffected by the use of different surface materials.

In addition, this paper summarizes the results of oil adhesion testing carried out primarily in the past year. The relationships of oil adhesion to other oil properties (hydrocarbon groups, viscosity, pour point, density, and surface tension) are examined.

INTRODUCTION

Researchers studying the penetration of oil into shoreline sediments have identified oil adhesiveness as a possible influencing factor. To provide a measure of this property, a test was developed by the Emergencies Science Division of Environment Canada. For the purpose of this test, oil adhesion is defined as the mass of oil per unit area, remaining on a standard test surface, after a defined time, under prescribed conditions.

METHODS

Standard Adhesion Test

The standard adhesion test procedure is described in detail in a previous paper (Jokuty *et al.*, 1995). Briefly, the standard test uses a stainless steel penetrometer needle as the test surface. The needle is dipped into the oil and then allowed to drain for 30 minutes. The mass of oil remaining on the needle, and the surface area of the needle are used to calculate the adhesion value.

Modified Adhesion Test

A modified test procedure was used to conduct adhesion tests with different surface materials. The test procedure was identical to the standard procedure, except for the use of the different materials. The materials tested, in addition to the standard stainless steel needle, were as follows:

a) Glass stirring rods (125 mm x 3 mm diameter)
b) Teflon stirring rods (150 mm x 8 mm diameter)
c) Wooden applicator sticks (145 mm x 2 mm diameter)
d) Plastic (polyethylene) rods (110 mm x 3 mm diameter)
e) Ceramic rods (145 mm x 10 mm diameter

Wood and plastic test materials were disposed of after a single use. Glass, Teflon, and ceramic materials were cleaned with dichloromethane. Efforts were made to minimize the reuse of these rods. A minimum of five measurements were made using each material with each test oil. The test oils were:
a) Alberta Sweet Mixed Blend Reference #4
b) IFO 180
c) IFO 300
d) Lucula
e) Point Arguello Comingled

Other Properties

Density, viscosity, pour point, and surface tension were measured according to the procedures described by Jokuty, Fingas, and Whiticar (1994). Hydrocarbon groups were determined as described by Jokuty *et al.* (1995).

RESULTS

Effect of Different Test Materials on Adhesion

Table 1 summarizes the data collected from this experiment. The oils are sorted alphabetically, then by adhesion. The following information is also included: adhesion test material, hydrocarbon groups (saturates, aromatics, resins, asphaltenes), density, viscosity, pour point, and surface tension.

Table 1 Data from Adhesion Experiment Using Different Test Surface Materials

Oil Name	test material	adhesion (g/m2)	saturates (wt %)	aromatics (wt %)	resins (wt %)	asphaltenes (wt %)	density @15 °C (g/mL)	viscosity @15 °C (mPa·s)	pour point (°C)	surface tension @15 °C (mN/m)
ASMB Ref. #4	Steel	13	65	27	5	3	0.8434	7	-27	25.8
ASMB Ref. #4	Plastic	23	65	27	5	3	0.8434	7	-27	25.8
ASMB Ref. #4	Glass	26	65	27	5	3	0.8434	7	-27	25.8
ASMB Ref. #4	Teflon	30	65	27	5	3	0.8434	7	-27	25.8
ASMB Ref. #4	Ceramic	33	65	27	5	3	0.8434	7	-27	25.8
ASMB Ref. #4	Wood	45	65	27	5	3	0.8434	7	-27	25.8
IFO 180	Steel	49	29	51	11	10	0.9670	2324	-10	31.4
IFO 180	Teflon	67	29	51	11	10	0.9670	2324	-10	31.4
IFO 180	Glass	69	29	51	11	10	0.9670	2324	-10	31.4
IFO 180	Plastic	70	29	51	11	10	0.9670	2324	-10	31.4
IFO 180	Wood	88	29	51	11	10	0.9670	2324	-10	31.4
IFO 180	Ceramic	99	29	51	11	10	0.9670	2324	-10	31.4
IFO 300	Steel	91	26	52	12	10	0.9859	14470	-6	32.6
IFO 300	Glass	127	26	52	12	10	0.9859	14470	-6	32.6
IFO 300	Teflon	128	26	52	12	10	0.9859	14470	-6	32.6
IFO 300	Plastic	144	26	52	12	10	0.9859	14470	-6	32.6
IFO 300	Wood	147	26	52	12	10	0.9859	14470	-6	32.6
IFO 300	Ceramic	154	26	52	12	10	0.9859	14470	-6	32.6

Oil Name	test material	adhesion (g/m2)	saturates (wt %)	aromatics (wt %)	resins (wt %)	asphaltenes (wt %)	density @15 °C (g/mL)	viscosity @15 °C (mPa·s)	pour point (°C)	surface tension @15 °C (mN/m)
Lucula	Steel	43	67	22	8	4	0.8574	43	18	DNF*
Lucula	Teflon	52	67	22	8	4	0.8574	43	18	DNF
Lucula	Wood	56	67	22	8	4	0.8574	43	18	DNF
Lucula	Plastic	60	67	22	8	4	0.8574	43	18	DNF
Lucula	Glass	65	67	22	8	4	0.8574	43	18	DNF
Lucula	Ceramic	77	67	22	8	4	0.8574	43	18	DNF
Point Arguello Comingled	Steel	81	36	25	23	16	0.9248	533	-12	27.5
Point Arguello Comingled	Teflon	93	36	25	23	16	0.9248	533	-12	27.5
Point Arguello Comingled	Plastic	108	36	25	23	16	0.9248	533	-12	27.5
Point Arguello Comingled	Glass	110	36	25	23	16	0.9248	533	-12	27.5
Point Arguello Comingled	Wood	122	36	25	23	16	0.9248	533	-12	27.5
Point Arguello Comingled	Ceramic	127	36	25	23	16	0.9248	533	-12	27.5

*does not flow

Figures 1 to 5 show the results of adhesion tests using the six different test materials, for each of the five test oils.

Figure 1

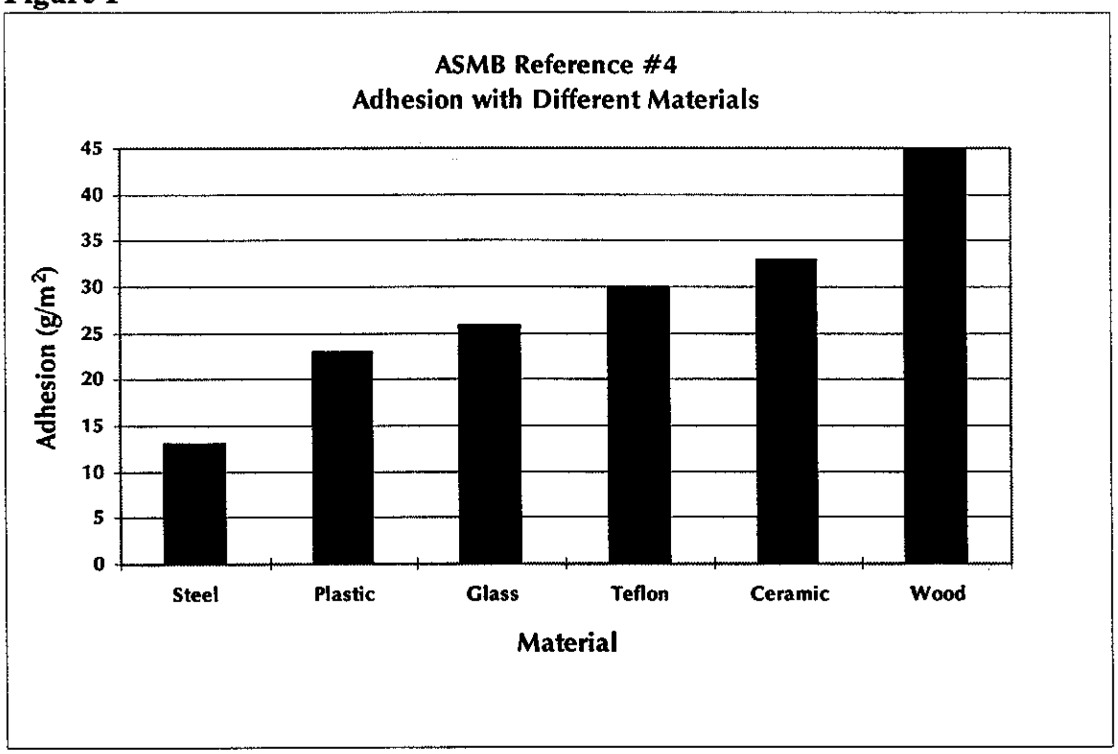


Figure 2

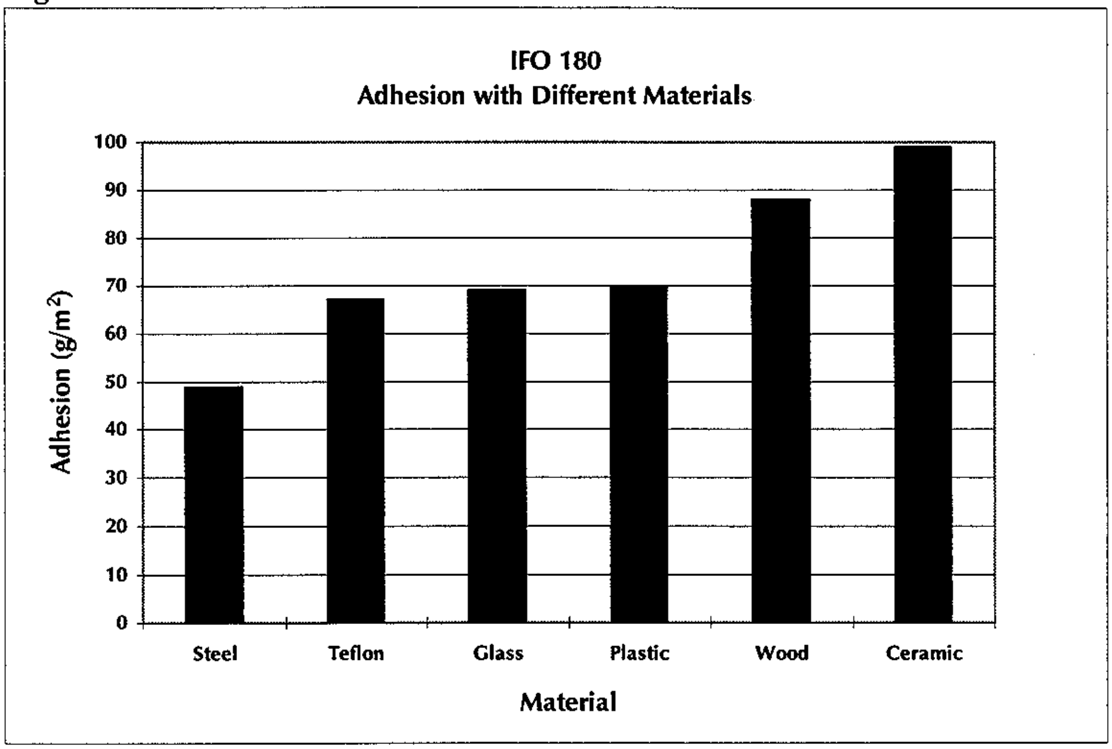


Figure 3

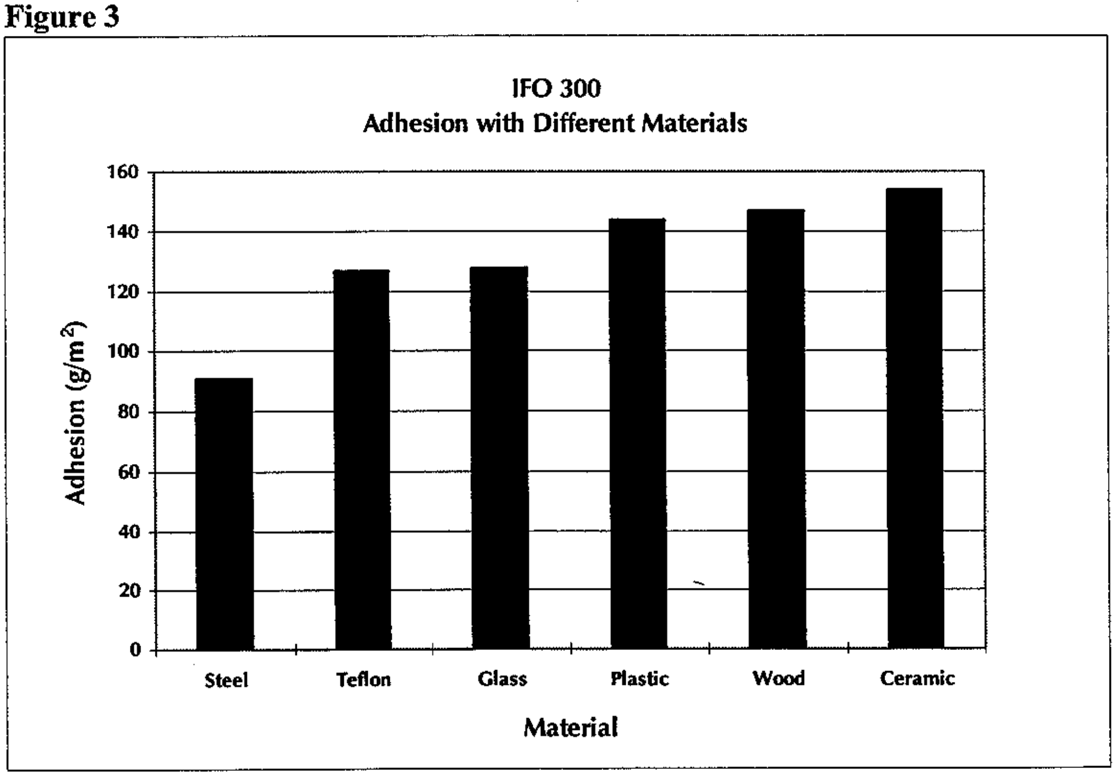


Figure 4

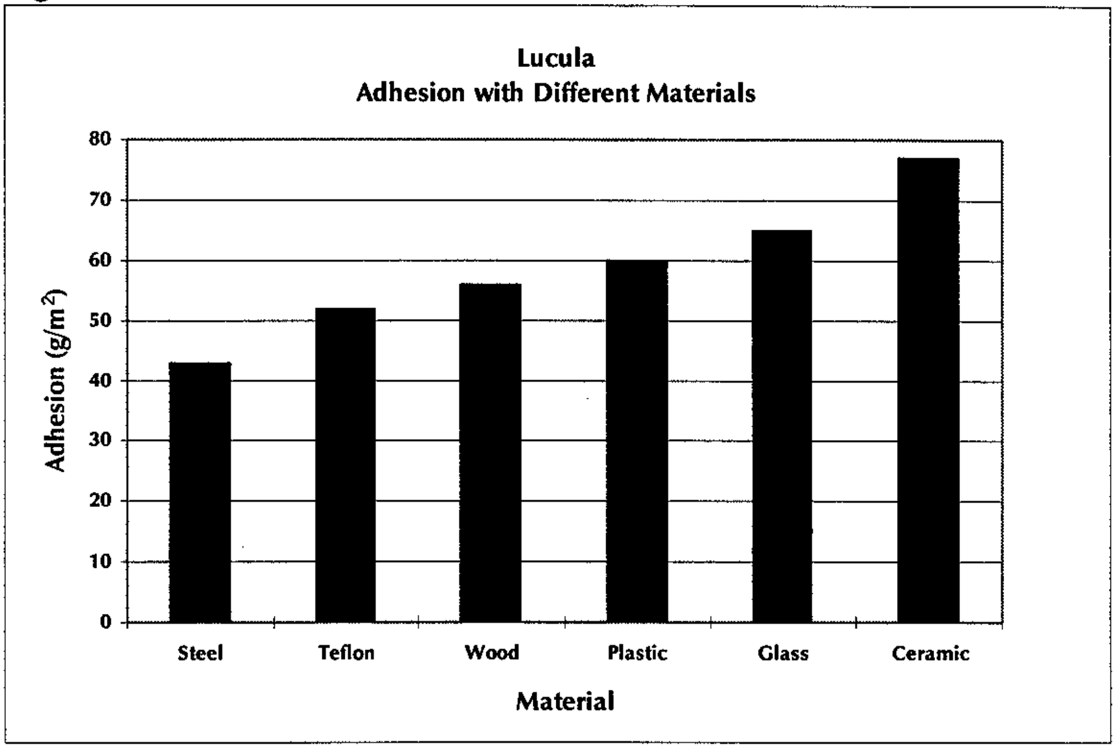
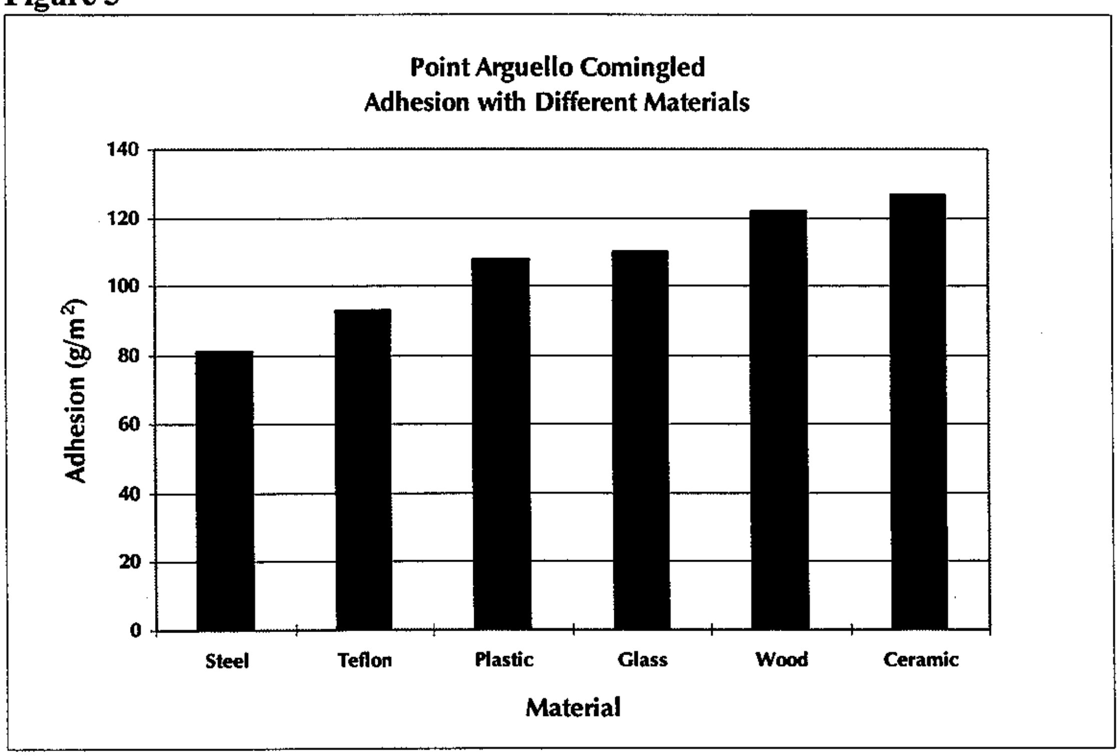


Figure 5



As can be seen from these figures, for each oil the range of adhesion values obtained using different materials is relatively small. In every case the stainless steel needle gave the lowest adhesion value, while the ceramic material gave the highest value for four of the five oils. Wood gave the highest adhesion value for one oil, and the second highest value for three oils. Plastic, glass, and Teflon tended to give intermediate values for all five oils. *Most importantly*, the relative order of adhesiveness of the oils remains the same regardless of which test material was used, i.e. (in ascending order) ASMB, Lucula, IFO 180, Point Arguello Comingled, IFO 300.

Figures 6 and 7 summarize the results of the materials experiment grouped by oil and by material, respectively. Figure 6 shows clearly the narrow range of values found for each oil, and Figure 7 illustrates how the relative order of adhesiveness of the oils remains constant regardless of which test material was used.

Figure 6

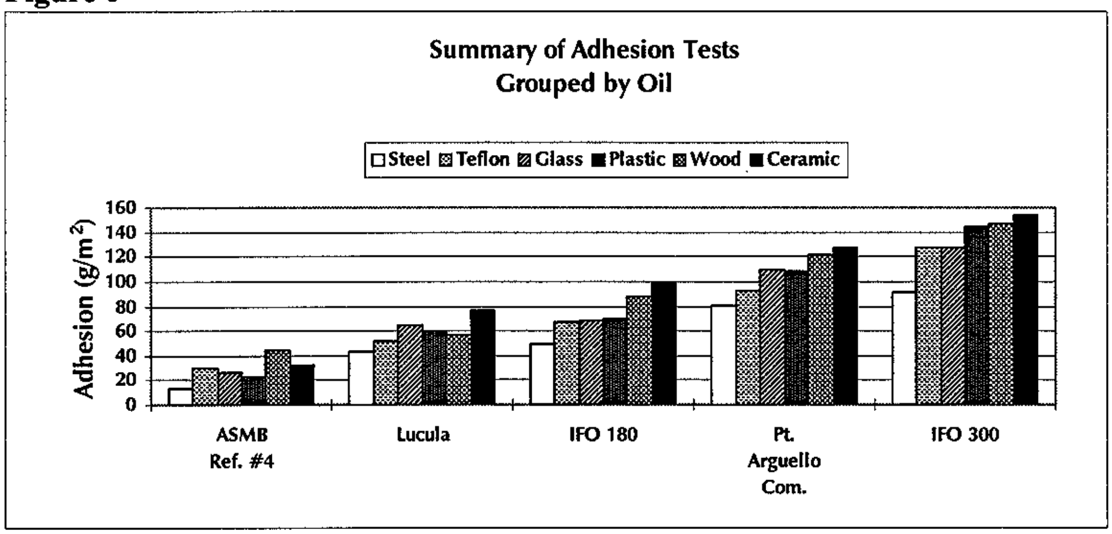
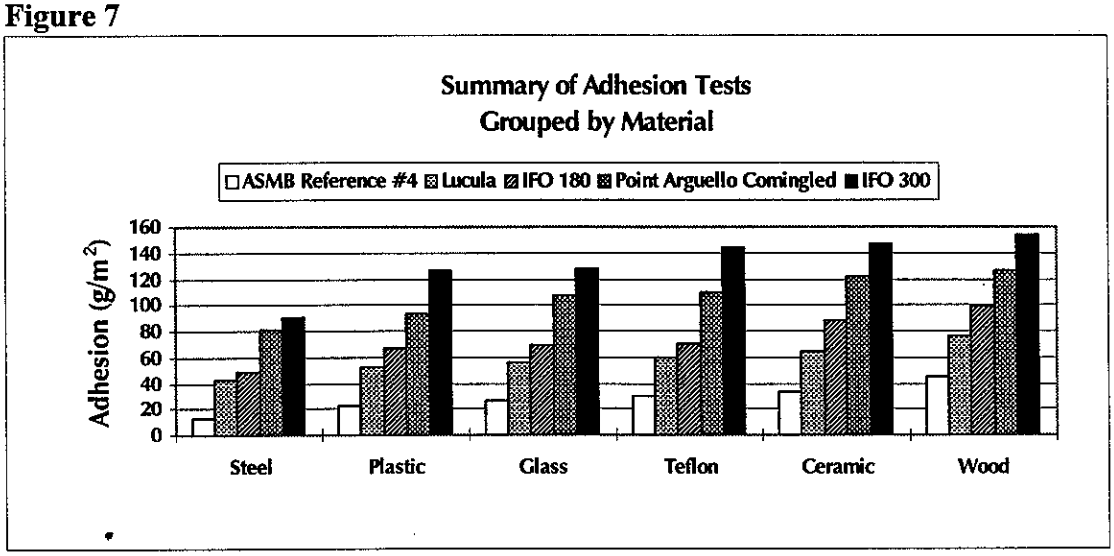
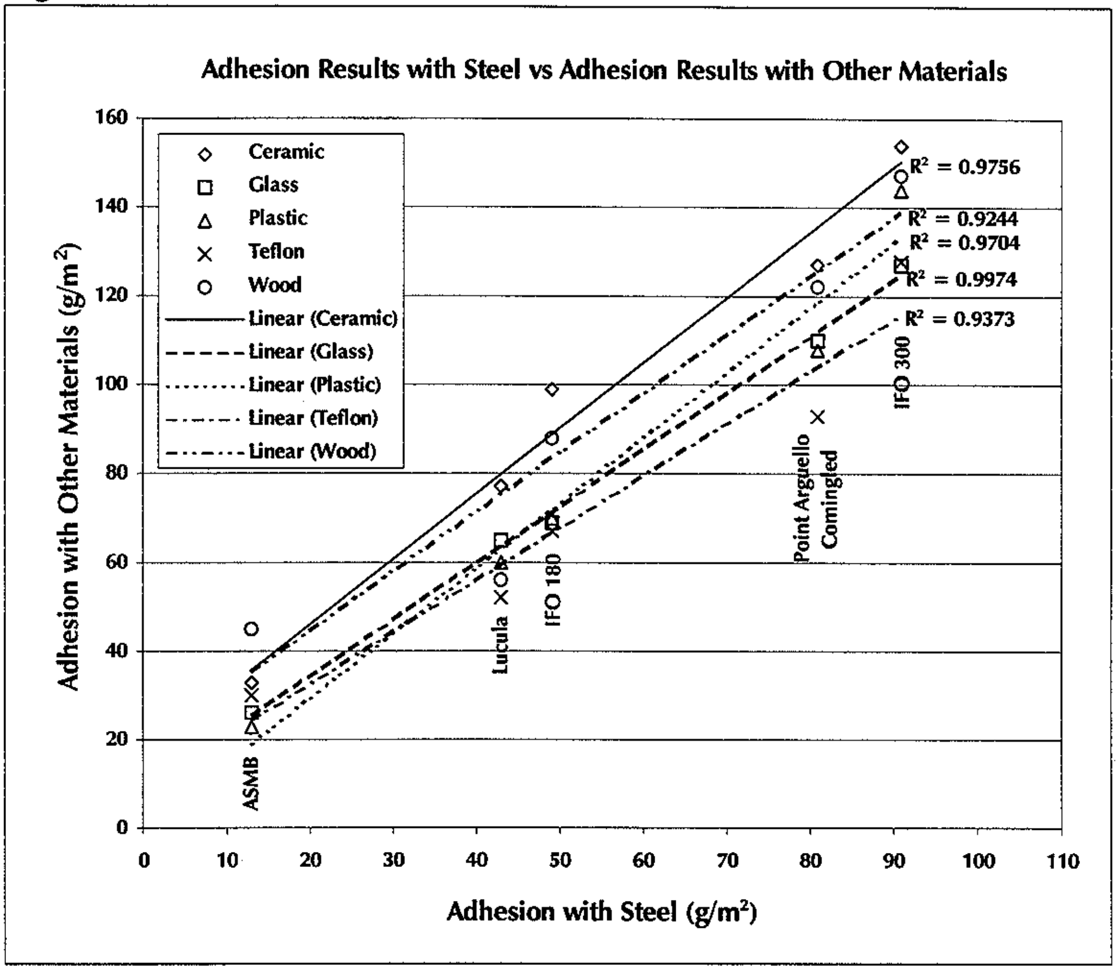


Figure 7



Finally, Figure 8 shows how the adhesion values measured with the five non-standard materials correlate with the values obtained using the standard stainless steel needle, across the five test oils.

Figure 8



Summary of Results from Standard Adhesion Test

Table 2 contains many of the results of standard adhesion testing carried out by the Emergencies Science Division, primarily in the past year. Data has been included for both fresh and evaporated oils, and limited to those oils for which the percent standard deviation of the adhesion values was not more than 20%, and for which the hydrocarbon groups analysis had also been performed.The oils are sorted alphabetically, then by evaporation, and then by adhesion. The following information is also included: hydrocarbon groups (saturates, aromatics, resins, asphaltenes), density, viscosity, pour point, and surface tension.

Table 2 Adhesion and Other Properties for Various Fresh and Evaporated Oils

Oil Name	evap (wt %)	adhesion (g/m2)	saturates (wt %)	aromatics (wt %)	resins (wt %)	asphaltenes (wt %)	density @15 °C (g/mL)	viscosity @15 °C (mPa·s)	pour point (°C)	surface tension @15 °C (mN/m)
Alaska North Slope	15	19	52	38	7	3	0.8976	38		
Arabian Medium	0	26	54	32	7	6	0.8783	29	-10	27.0
Arabian Medium	13	28	42	44	7	7	0.9102	91	-4	28.7
Arabian Medium	21	39	40	46	8	7	0.9263	275	-2	29.9
Arabian Medium	31	65	27	54	9	10	0.9495	2160	7	31.3
ASMB Ref. #4	0	13	65	27	5	3	0.8434	7	-27	25.8
ASMB Ref. #4	14	22	60	31	6	3	0.8712	15	-9	28.2
ASMB Ref. #4	26	35	56	34	6	3	0.8902	44	3	28.5
ASMB Ref. #4	39	61	54	33	7	5	0.9078	168	14	30.6
Brent	0	12	72	23	4	1	0.8351	6	-6	25.5
Eugene Island Block 32	0	10	84	14	2	1	0.8399	10	7	27.5
Eugene Island Block 32	6	13	81	16	2	1	0.8418	9	9	28.5
Eugene Island Block 32	13	20	82	15	2	1	0.8453	16	12	27.9
Eugene Island Block 32	20	20	81	16	3	1	0.8481	21	13	27.9
Eugene Island Block 43	0	18	81	16	3	1	0.8404	13	0	27.5
Eugene Island Block 43	7	19	78	17	4	1	0.8518	21	7	28.5
Eugene Island Block 43	16	20	77	15	7	1	0.8594	36	7	29.2
Eugene Island Block 43	24	25	78	16	5	1	0.8665	65	11	29.7
Federated (1994)	18	11	70	24	4	2	0.8584	12		
Federated (1994)	27	13	71	25	3	1	0.8654	16		
Green Canyon Block 65	8	35	38	42	15	5	0.9509	457	-17	30.4
Green Canyon Block 65	23	77	32	45	16	8	0.9716	4250	-6	31.8
Green Canyon Block 109	0	23	51	39	9	1	0.8921	39	-36	28.0
Green Canyon Block 109	8	25	46	43	10	1	0.9101	98	-27	29.7
Green Canyon Block 109	14	27	44	44	11	1	0.9218	225	-21	30.7
Green Canyon Block 109	22	34	42	43	14	1	0.9341	690	-16	31.2
Gullfaks	0	23	59	35	5	1	0.8701	13	-32	27.7
Gullfaks	10	35	58	35	6	1	0.8891	31	-32	29.5
Hibernia	18	26	59	33	6	2	0.8750	80 @100/s		
Hibernia	26	34	58	34	6	2	0.8849	161 @100/s		
High Viscosity Fuel Oil	0	129	18	43	13	26	1.0140	13460	2	32.9
IFO 180	0	49	29	51	11	10	0.9670	2324	-10	31.4
IFO 180	2	63	32	45	12	11	0.9685	3232		
IFO 180	8	129	28	39	17	15	0.9840	27280	6	33.1
IFO 300	0	91	26	52	12	10	0.9859	14470	-6	32.6
IFO 300	5	358	24	28	30	17	0.9996	220000	12	NM*
Louisiana	0	18	73	21	4	1	0.8518	8	-28	25.9
Louisiana	10	22	69	25	5	0	0.8696	16	-23	28.3
Louisiana	21	27	66	27	6	0	0.8837	36	-12	29.6
Louisiana	32	34	64	29	7	0	0.8953	80	-8	30.2
Lucula	0	43	67	22	8	4	0.8574	43	18	DNF**
Lucula	11	115	64	23	8	4	0.8821	34030 @1/s	28	DNF
Lucula	15	116	62	26	9	4	0.8904	51650 @1/s	30	DNF
Lucula	27	369	59	26	12	4	0.9050	230300 @1/s	32	DNF
Main PassBlock 37	30	38	70	23	6	1	0.8689	36	15	29.0
Main Pass Block 37	50	52	66	24	8	2	0.8855	115	17	31.2

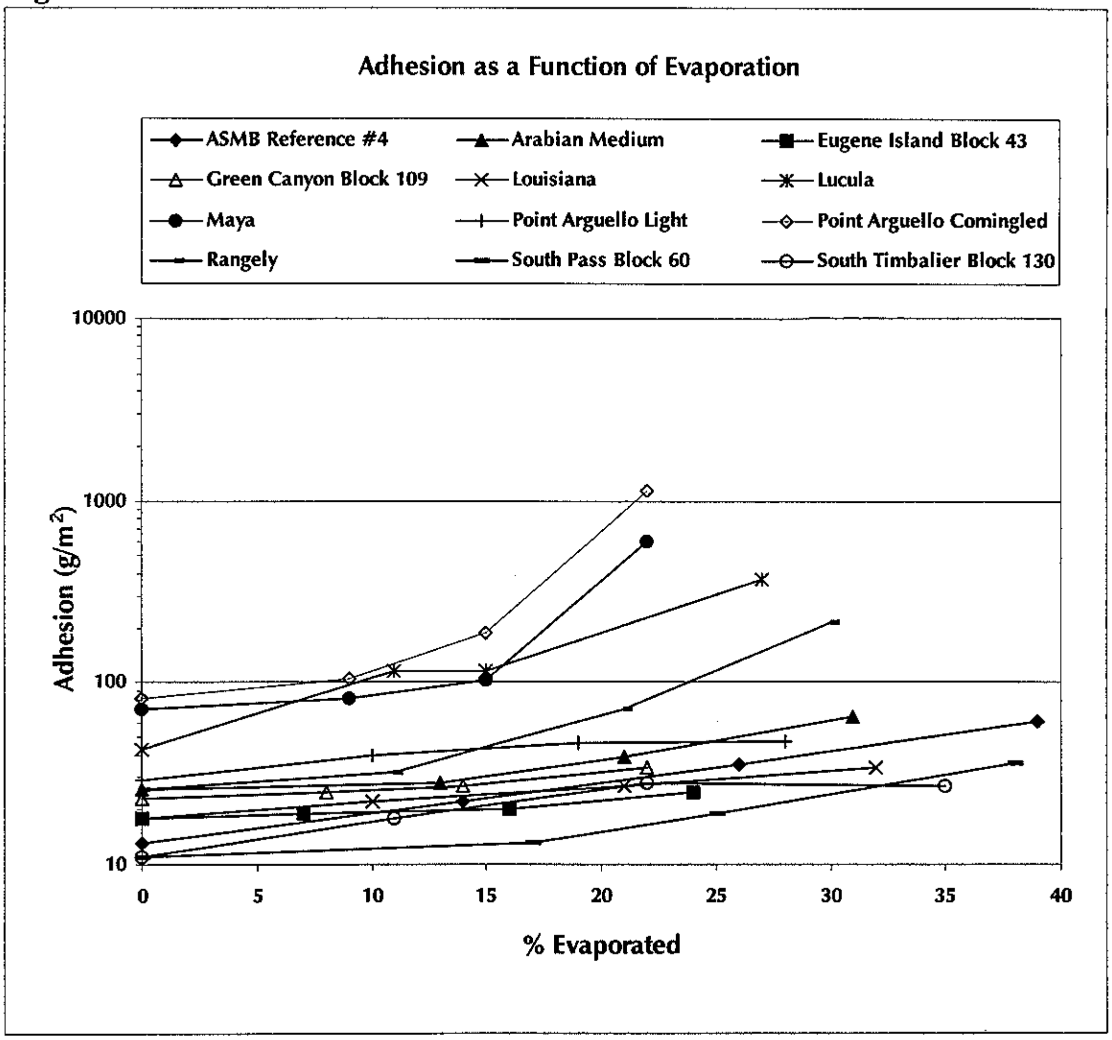
Oil Name	evap (wt %)	adhesion (g/m2)	saturates (wt %)	aromatics (wt %)	resins (wt %)	asphaltenes (wt %)	density @15 °C (g/mL)	viscosity @15 °C (mPa·s)	pour point (°C)	surface tension @15 °C (mN/m)
Main Pass Block 306	12	14	63	29	8	1	0.8849	19	-35	28.7
Main Pass Block 306	24	28	58	32	10	1	0.9034	54	-32	30.1
Main Pass Block 306	37	41	55	33	11	1	0.9203	219	-16	31.2
Maya	0	71	38	39	8	16	0.9255	280	-15	28.2
Maya	9	82	33	41	8	18	0.9515	1980	-9	29.7
Maya	15	102	31	41	10	17	0.9657	8670	-2	30.9
Maya	22	595	28	39	11	22	0.9868	405000	17	DNF
Mississippi Canyon Block 194	10	10	71	23	6	0	0.8655	11	-28	28.5
Mississippi Canyon Block 194	21	22	69	24	6	0	0.8762	21	-22	29.6
Mississippi Canyon Block 194	35	41	67	26	7	0	0.8874	51	16	30.3
Point Arguello Comingled	0	81	36	25	23	16	0.9248	533	-12	27.5
Point Arguello Comingled	9	104	31	33	19	17	0.9528	4988	-7	30.2
Point Arguello Comingled	15	187	27	33	21	19	0.9688	41860	7	NM
Point Arguello Comingled	22	1137	24	33	21	22	0.9853	2266000	28	DNF
Point Arguello Heavy	0	155	32	32	17	19	0.9447	3250	-4	23.8
Point Arguello Heavy	9	276	26	35	18	20	0.9706	59380	6	NM
Point Arguello Heavy	18	1231	25	34	21	22	0.9914	4953000	30	DNF
Point Arguello Light	0	29	57	27	9	7	0.8739	22	-22	27.1
Point Arguello Light	10	40	54	30	9	8	0.8979	76	-12	28.9
Point Arguello Light	19	46	48	31	12	9	0.9132	183	-12	29.9
Point Arguello Light	28	47	45	32	12	11	0.9289	671	8	31.0
Rangely	0	26	71	21	5	4	0.8567	33	17	27.1
Rangely	11	32	68	24	5	3	0.8765	61	18	28.4
Rangely	21	71	65	24	6	4	0.8920	173	21	29.8
Rangely	30	214	61	27	6	6	0.9059	30400 @1/s	29	DNF
Ship Shoal Block 269	13	15	71	23	5	0	0.8517	7	-19	27.5
Ship Shoal Block 269	26	25	69	24	6	1	0.8657	18	-20	28.6
Ship Shoal Block 269	39	30	67	26	6	1	0.8796	44	-2	29.9
South Pass Block 60	0	11	71	20	8	1	0.8453	9	-9	26.8
South Pass Block 60	17	13	67	26	7	1	0.8709	22	-3	28.7
South Pass Block 60	25	19	64	27	8	1	0.8809	41	9	29.4
South Pass Block 60	38	36	61	28	9	2	0.8979	161	12	30.3
South Pass Block 93	11	15	74	20	4	2	0.8637	23	8	29.0
South Pass Block 93	21	24	73	21	4	2	0.8698	32	12	29.6
South Pass Block 93	34	40	71	22	5	3	0.8832	80	16	30.4
South Timbalier Block 130	0	11	78	16	5	0	0.8487	7	-27	26.5
South Timbalier Block 130	11	18	72	22	5	0	0.8632	10	-23	28.4
South Timbalier Block 130	22	28	71	23	6	0	0.8748	19	-18	29.2
South Timbalier Block 130	35	27	68	23	8	1	0.8877	48	-9	30.2
Statfjord	0	14	68	26	5	1	0.8354	6	-2	26.1

*not measurable **does not flow

Effect of Evaporation

Figure 9 shows the effect of evaporation on oil adhesion for those oils in Table 2 which have a complete set of data. In general, the lighter oils tend to display a fairly limited change in adhesion even when heavily evaporated, while the heavier oils (Maya, Point Arguello Comingled, Lucula) tend to have a sudden increase in adhesion after moderate evaporation. For nearly all the oils tested, the adhesion range, as a function of evaporation for each oil, falls within one order-of-magnitude.

Figure 9



Relationships of Other Properties to Adhesion

Hydrocarbon Groups

Figures 10 to 13 show adhesion as a function of saturate, aromatic, resin, and asphaltene contents, respectively. Only data from fresh oils have been included in these figures. If data from both fresh and evaporated oils are considered, then the correlations to hydrocarbon groups become much poorer (Figures 14 to 17).

Figure 10

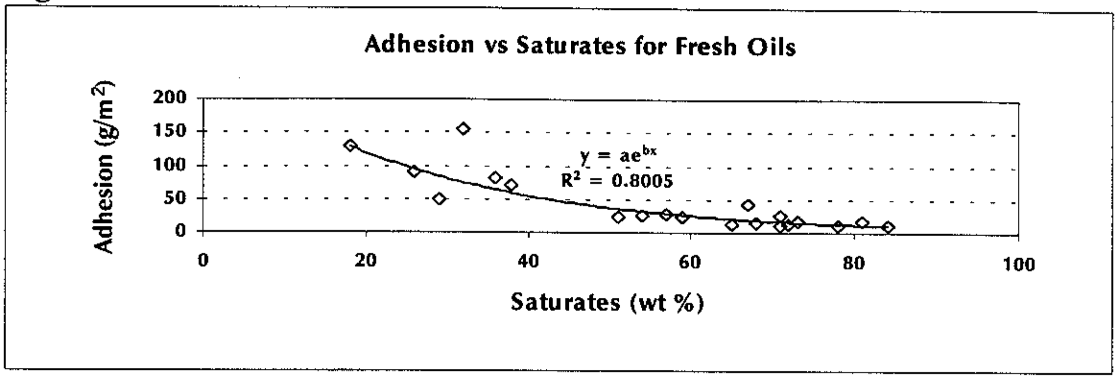


Figure 11

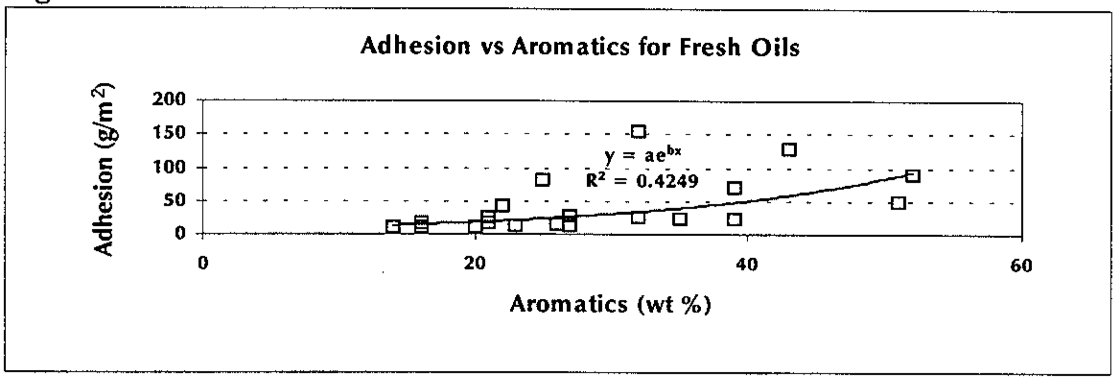


Figure 12

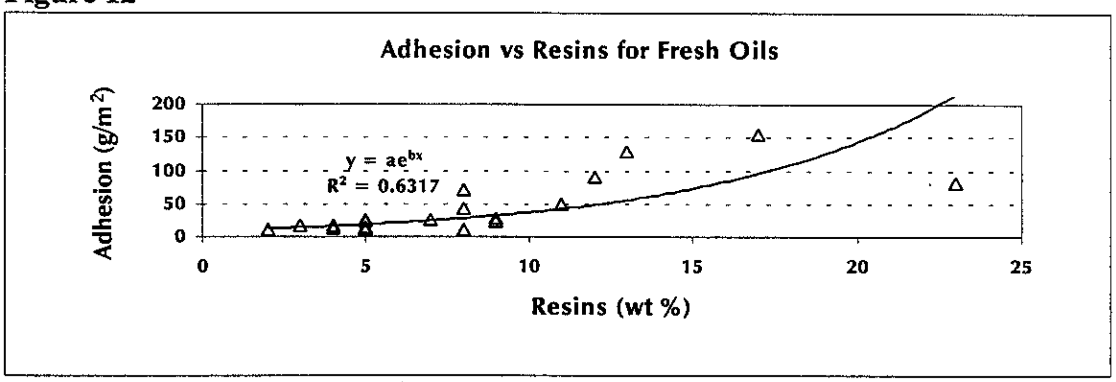


Figure 13

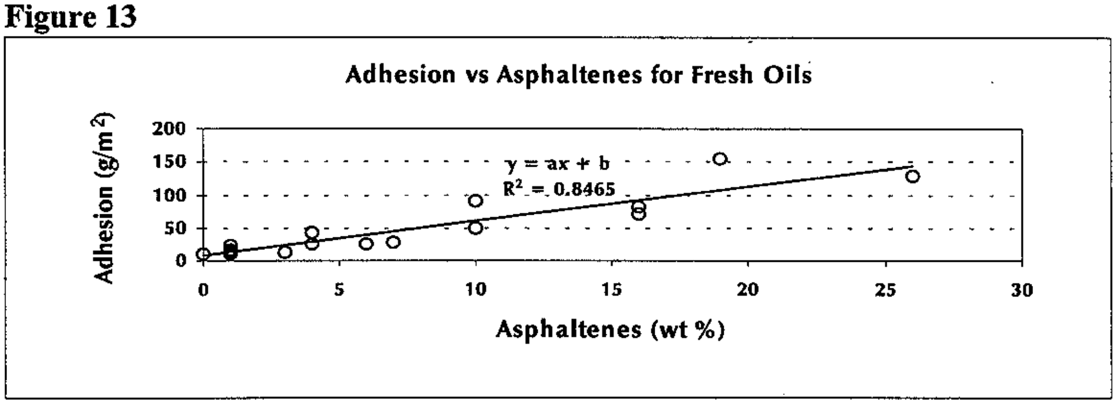


Figure 14

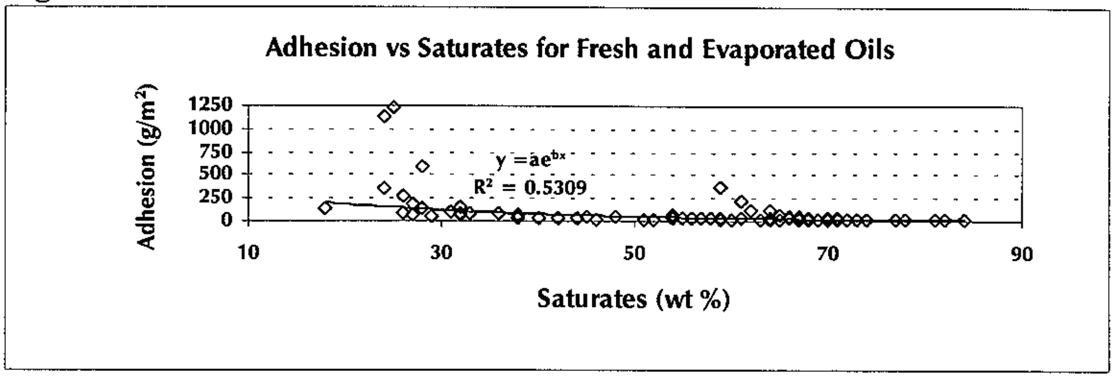


Figure 15

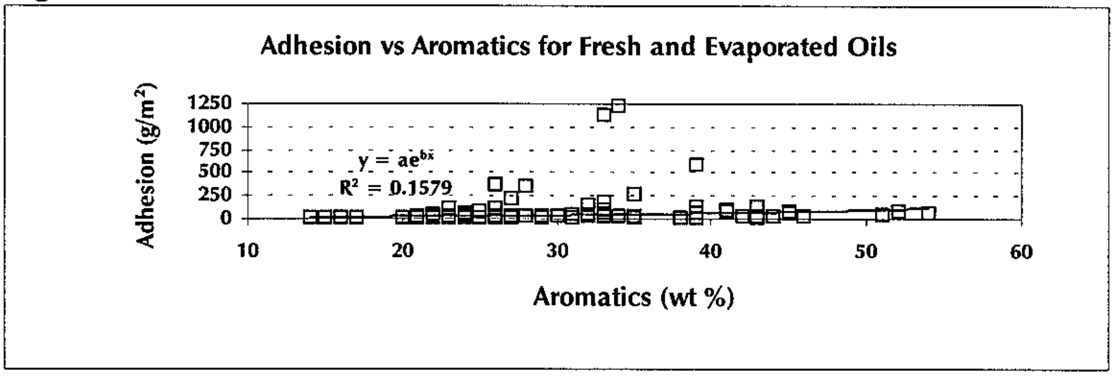


Figure 16

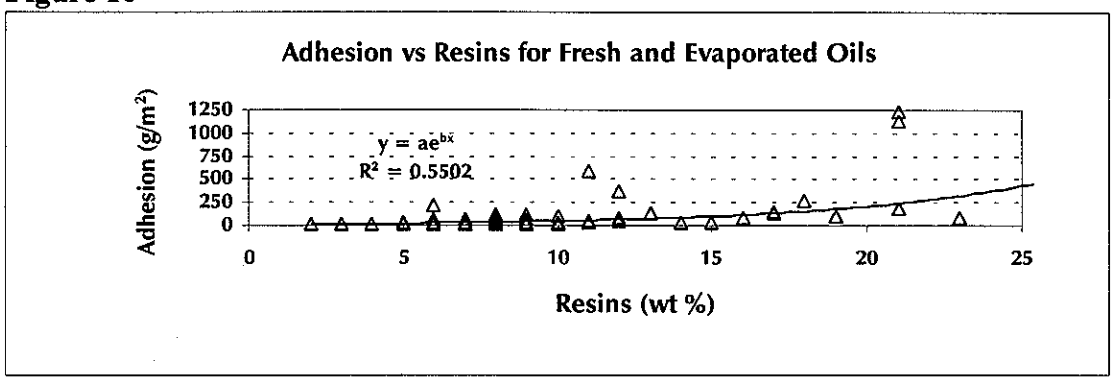
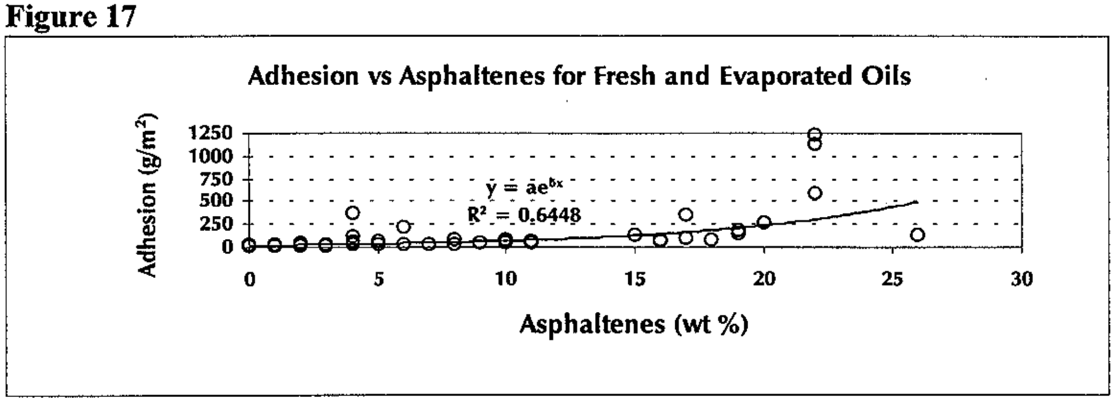


Figure 17



Viscosity

Figure 18 shows the relationship between adhesion and viscosity for fresh oils only. Figure 19 shows the relationship between adhesion and viscosity for fresh and evaporated oils.

Figure 18

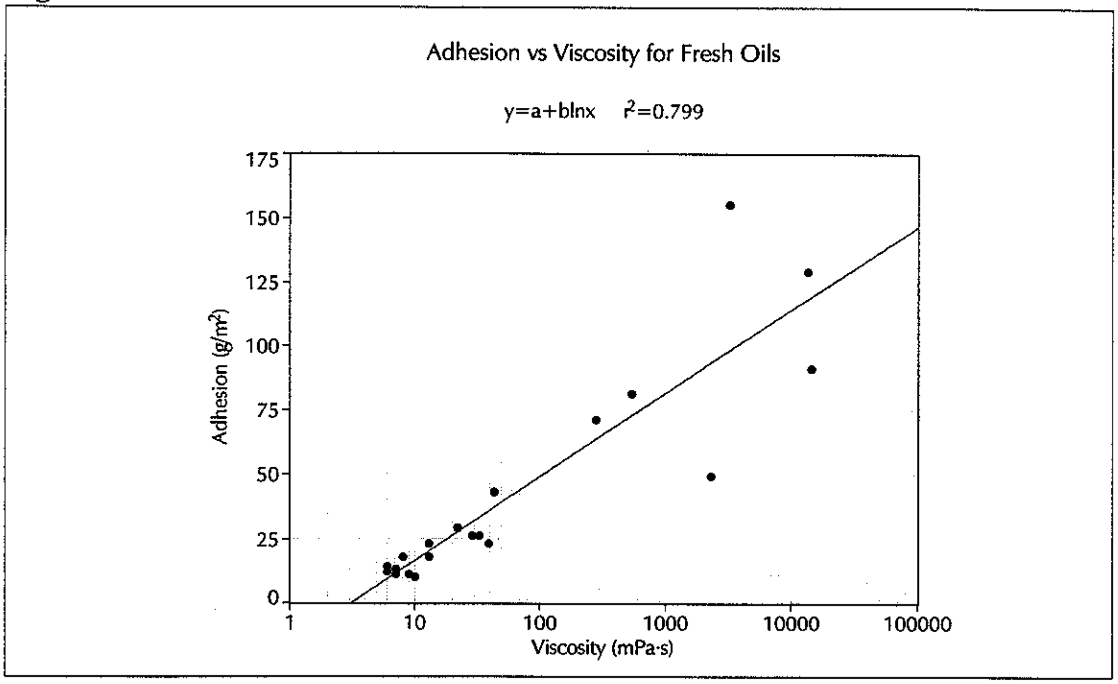
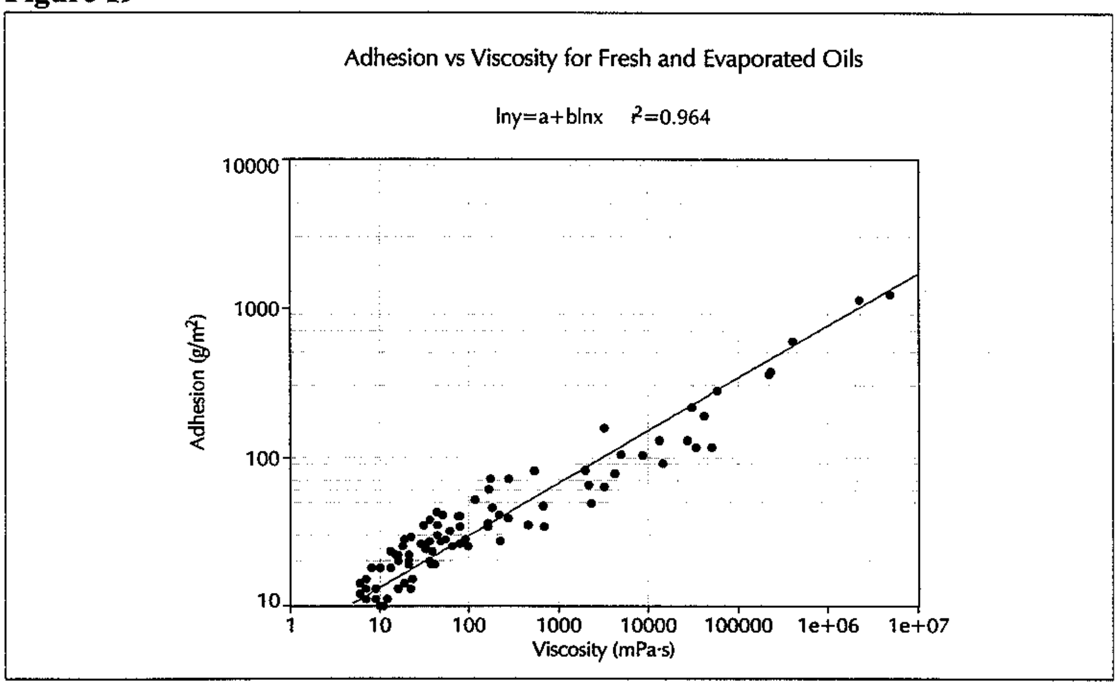


Figure 19



Density

Figure 20 shows an inverse relationship between adhesion and density, for fresh oils, but Figure 21 shows that there is no clear relationship when both fresh and evaporated oils are considered.

Figure 20

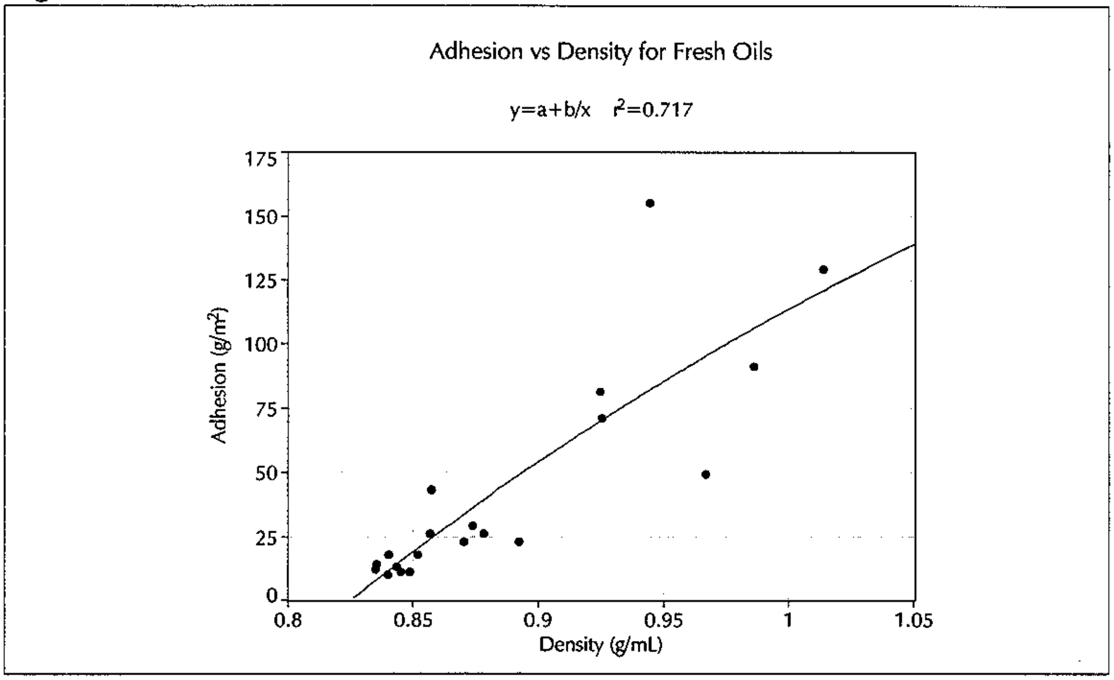
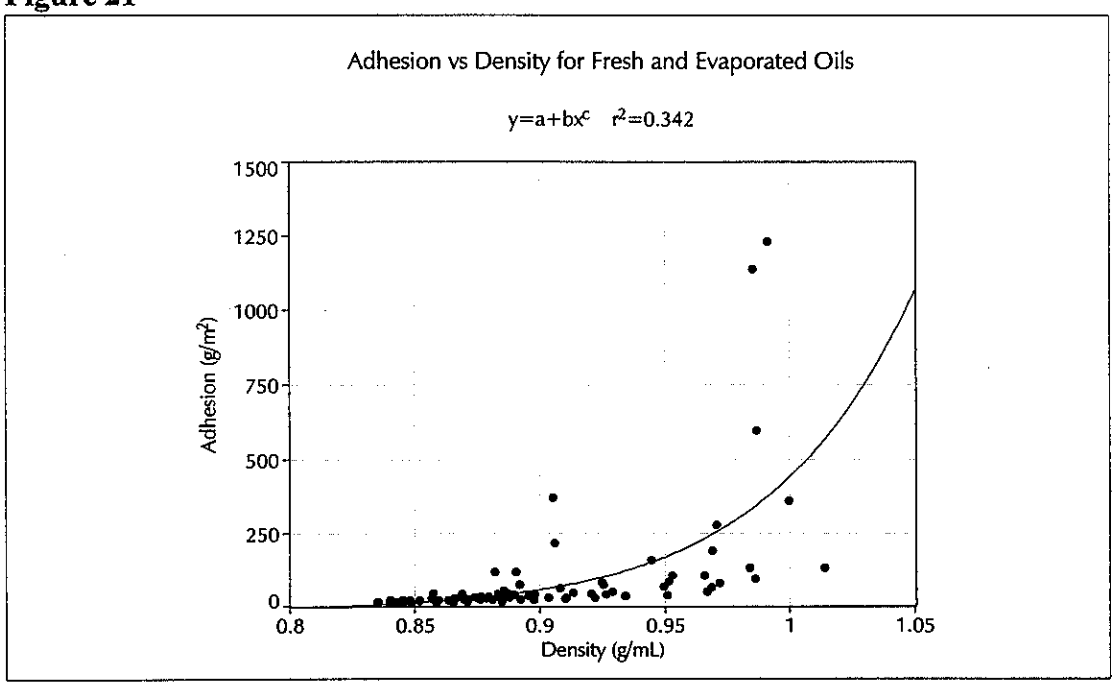


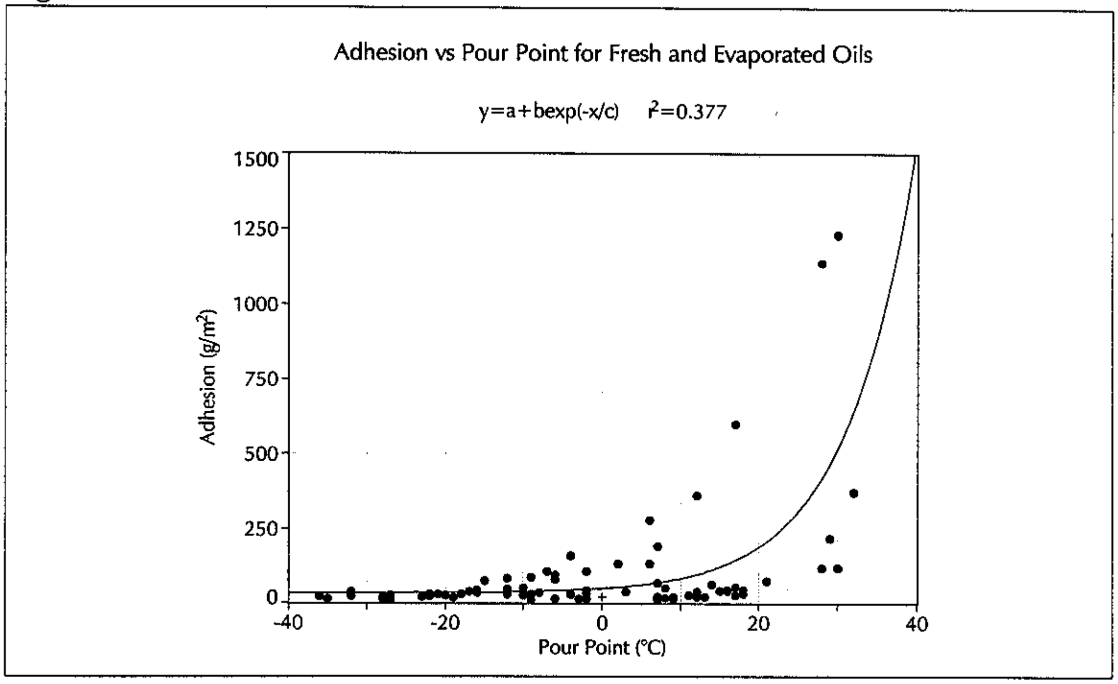
Figure 21



Pour Point

Figure 22 shows the poor correlation between pour point and adhesion.

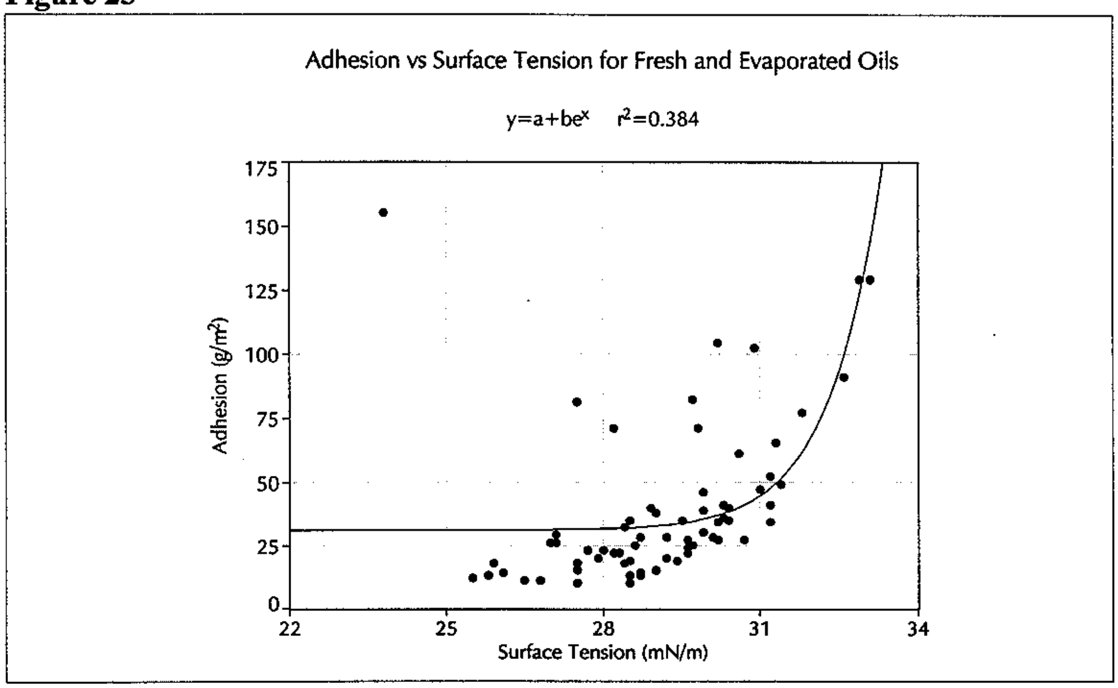
Figure 22



Surface Tension

Figure 23 shows the poor correlation between surface tension and adhesion.

Figure 23



DISCUSSION

As can be seen from the preceding figures, reasonably clear relationships exist between adhesion and hydrocarbon groups, viscosity, and density, for fresh oils. When evaporated oils are considered together with fresh oils, most correlations between adhesion and other properties worsen. Viscosity is the exception to this rule, showing a substantially improved correlation to adhesion when both fresh and evaporated oils are considered.

For oils in general, oil adhesion exhibits few good correlations with other properties. However, for individual oils, the trends are much better. Figures 24 to 26 demonstrate this for fresh and evaporated Alberta Sweet Mixed Blend Reference #4 crude oil.

Figure 24

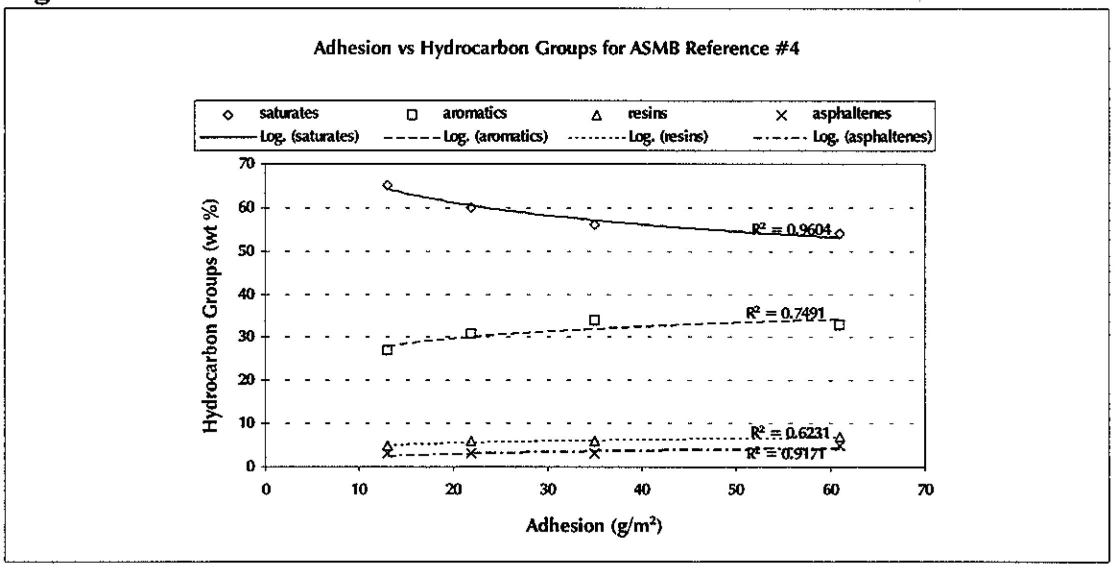


Figure 25

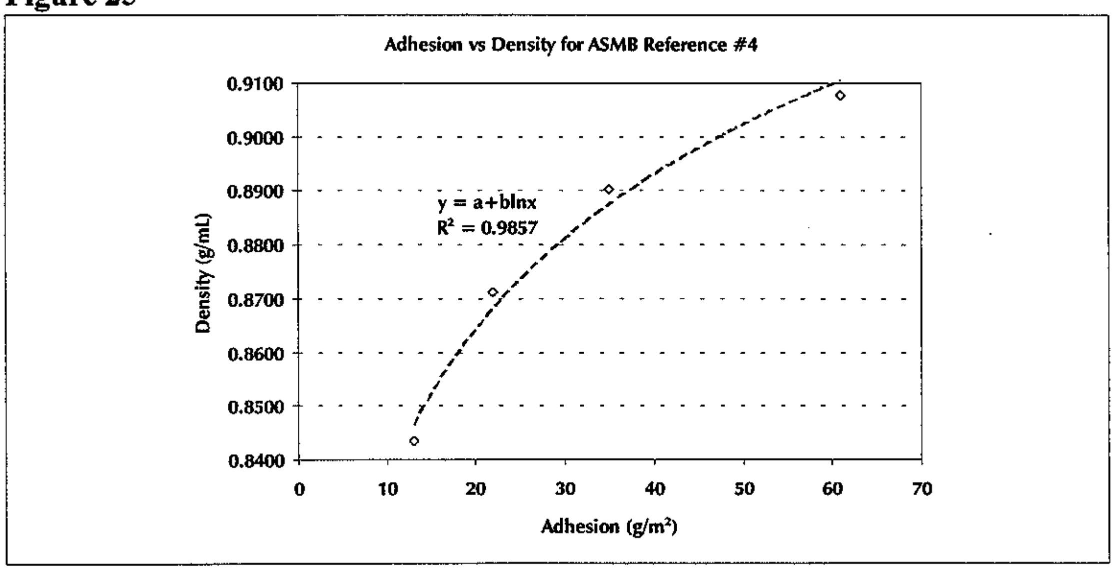
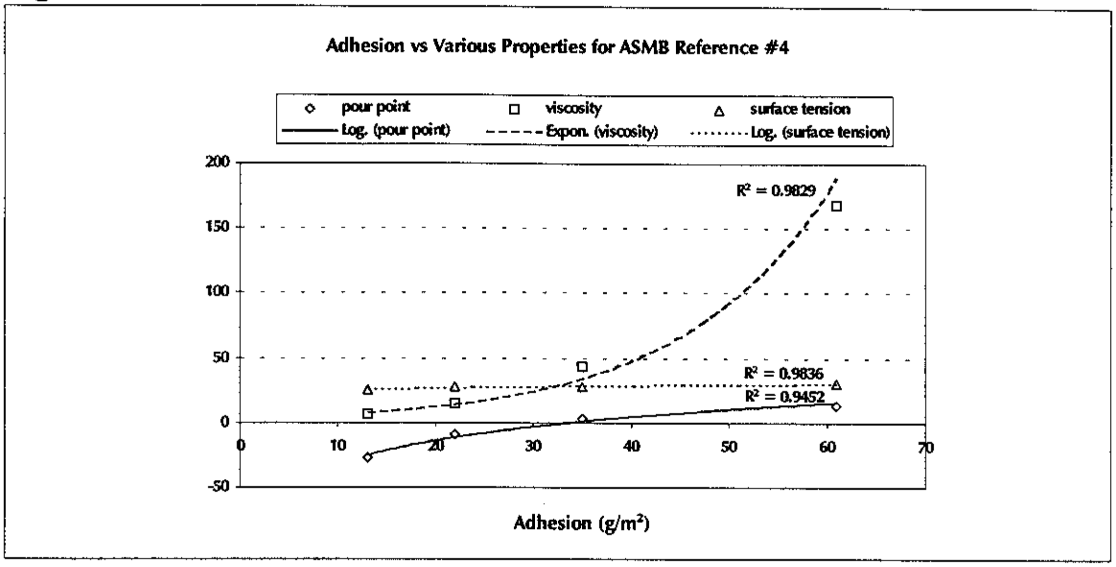


Figure 26



As the preceding three figures show, most properties of an individual oil will follow smooth trends as the oil is weathered, and so these properties will correlate well to each other. Heavier oils, often prove to be more problematic. Figures 27 to 30 show various properties correlated to adhesion for fresh and evaporated Maya crude oil. In spite of the fact that this is a heavy oil, most of the properties shown correlate quite well to adhesion.

Figure 27

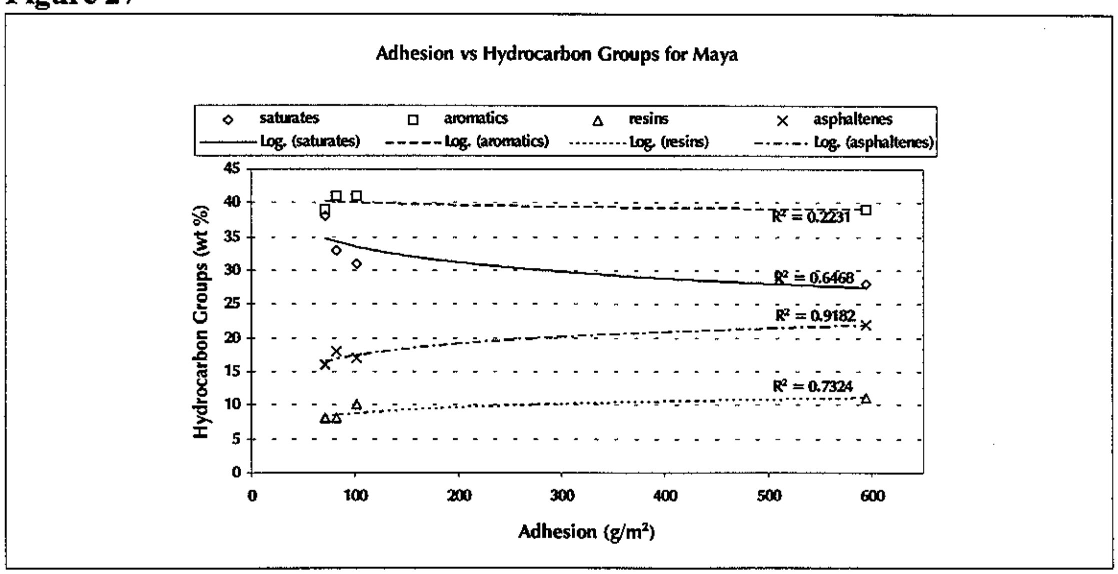


Figure 28

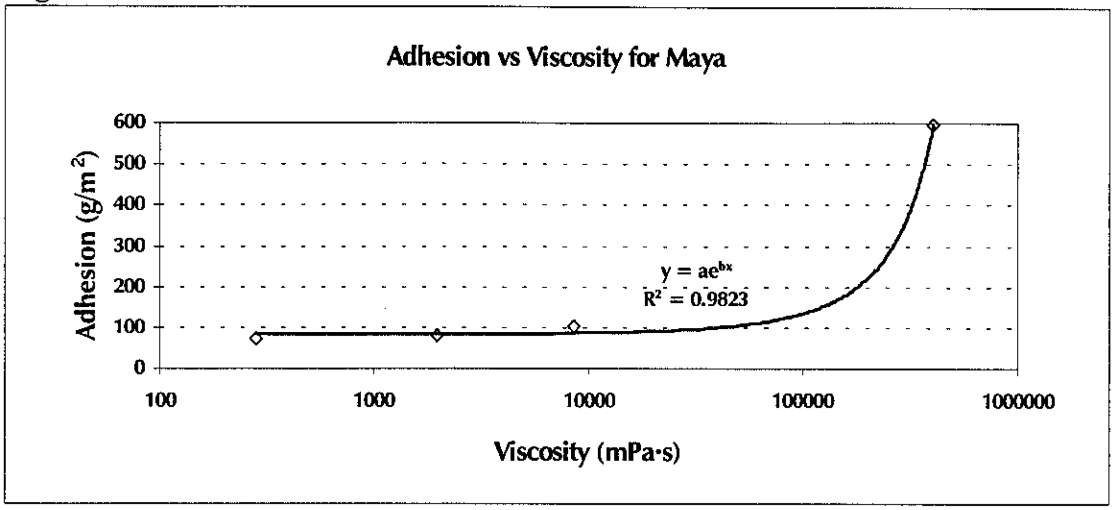


Figure 29

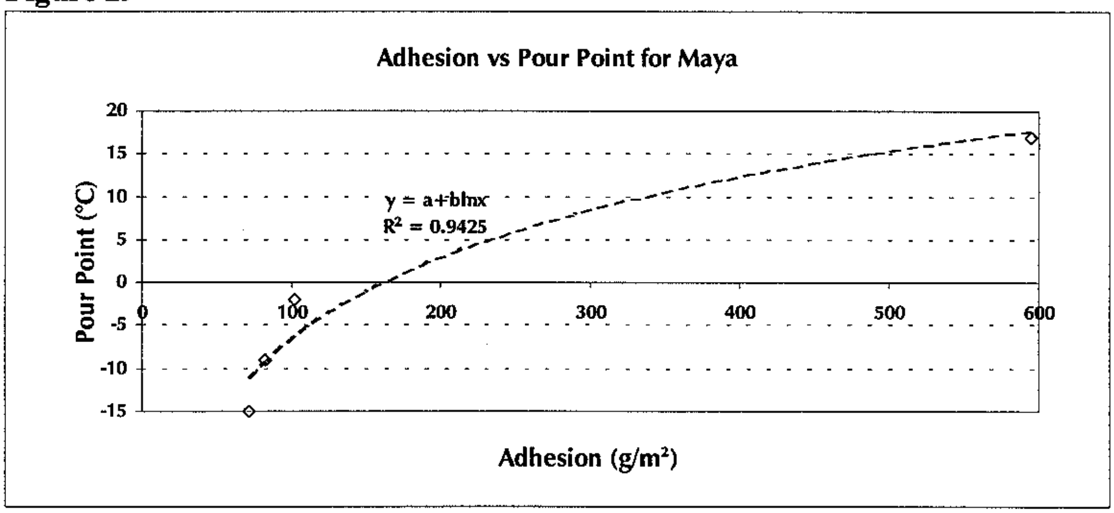
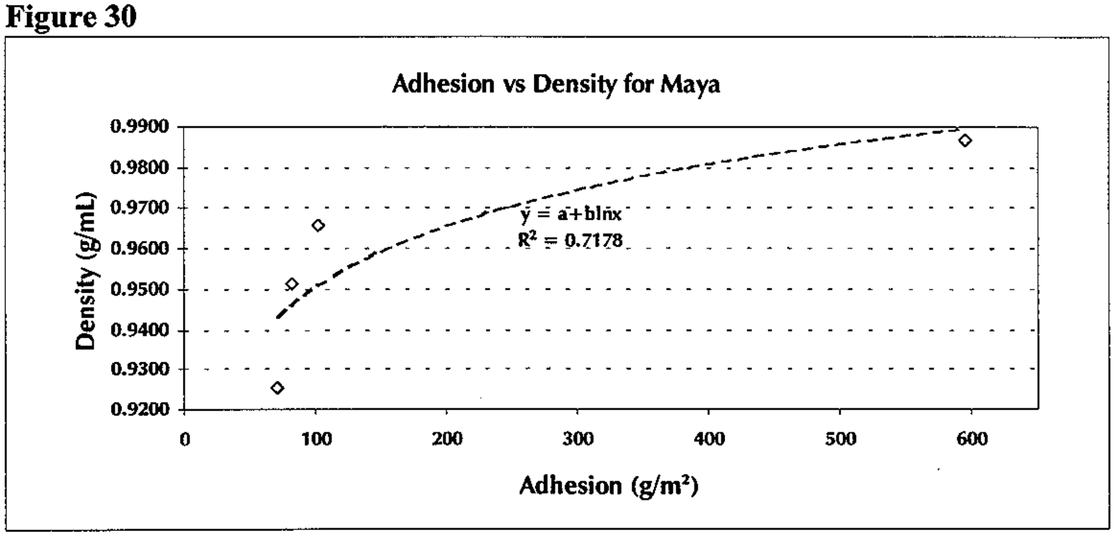


Figure 30



CONCLUSION

Based on the results of oil adhesion testing summarized in this report, the following conclusions can be drawn:

1. The relative order of adhesiveness of different oils is independent of the type of material used for the test surface.
2. For a given oil, adhesion values measured using different surface materials generally fall within one order-of-magnitude.
3. For both fresh and evaporated oils in general, there are a limited number of good correlations of adhesion with other oil properties. In particular, for fresh oils there are good correlations with asphaltene content, viscosity, and density. If both fresh and evaporated oils are considered, viscosity appears to show the strongest correlation.
4. Individual oils, from light to heavy, generally show good correlations between adhesion and other properties as the oil evaporates.

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